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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

SUMMARY OF COST ESTIMATES FOR PRODUCING ALUMINA FROM NON-BAUXITE SOURCES

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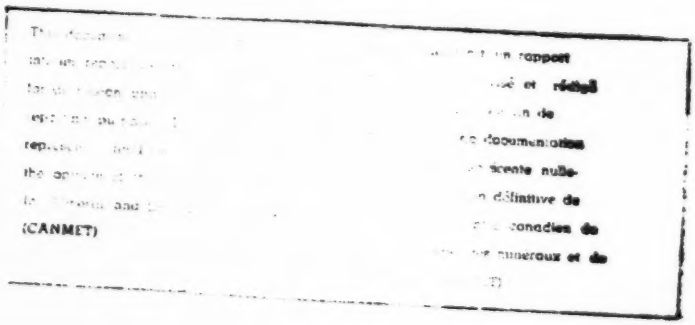

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SUMMARY OF COST ESTIMATES FOR PRODUCING ALUMINA FROM NON-BAUXITE SOURCES

by

J. Palmer

SUMMARY

The cost of producing alumina from Canadian non-bauxite sources using different processes has been estimated. The HCl-Caustic Purification process on coaly waste appears to be the best combination to produce cell grade alumina economically.

The cost of producing one tonne of alumina from Hat Creek coaly waste using the HCl-Caustic Purification and the Lime-Soda Sinter process is estimated at $223 and $257 per tonne respectively.

The cost of producing one tonne of alumina with the Bayer process from bauxite is estimated at $228.

RÉSUMÉ DU COÛT ESTAMATIF POUR LA PRODUCTION D'ALUMINE À PARTIR DES SOURCES NON-BAUXITIQUES

par

J. Palmer

SOMMAIRE

On a estimé le coût de produire de l'alumine au moyen de divers procédés à partir des sources canadiennes non-bauxitiques. Le procédé d'épuration caustique avec HCl des déchets charbonneux s'avère la méthode la plus économe pour la production d'alumine de bonne qualité.

On évalue le coût de produire une tonne d'alumine à partir des déchets charbonneux de Hat Creek au moyen de la méthode d'épuration caustique avec HCl et celle de chaux-frittage à 223 et 257$ le tonne respectivement.

On évalue le coût de produire une tonne d'alumine au moyen de la méthode Bayer à partir de la bauxite à 228$.

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INTRODUCTION

Canada is one of the major aluminum producers in the world and one of the largest importers of bauxite and alumina. The reason for this is the fact that there is no bauxite occurrence in Canada and all the raw material to make metallic aluminum must be imported. This situation prompted CANMET to study the possibility of producing alumina from non-bauxitic material which can be found in large quantity in Canada. The materials that have been studied are anorthosite, clay, fly ash and coaly waste from the Hat Creek coal deposit. Two main processing techniques were tried for extracting aluminum oxide from the above starting materials: acid leaching and alkaline sintering and leaching. The alumina used for aluminum making has to be of high quality and if produced from non-bauxitic raw material must be competitive with alumina produced from bauxite by the Bayer process. The above qualifications of course impose a high order of constraint on the process to be used for the extraction of alumina. Only those processes and raw materials that offer a certain amount of hope to fulfill the above requirements will be discussed in detail in this report.

POSSIBLE ALUMINA SOURCES IN CANADA (1)

Aluminum oxide accounts for about 16 weight per cent of the earth's crust, while good bauxite ores contain about 50 to 60 per cent alumina. An alternate source should generally contain at least 25 to 30 per cent alumina. Although abundant and widely distributed, alumina does not often occur in large quantities in high concentration, except in bauxite.

The most abundant potential Canadian source of alumina is anorthosite, a rock that occurs in large masses in several areas of Quebec and Labrador. Anorthosites of interest would contain at least 26 to 30% alumina, although most anorthosite occurrences contain less than this. There are, however, some high-alumina deposits known, for example, near Lac St Jean, Quebec, and Harp Lake, Laborador, and more probably could be found if an extensive exploration program were undertaken.

Kaolinitic clay is an alumina source that is attracting considerable attention in the southeastern United States, particularly in Georgia where there are very large deposits. Canada has no clay deposits of a comparable

size and grade, but in southern Saskatchewan there are clay beds 3.5 to 6 metres thick, with 25 to 29% alumina, underlain by a clay-sand mixture from which the clay could be upgraded. There could be as much as several hundred million tonnes of this clay, but a drilling program would be required to prove the reserves. Other clays of potential interest occur in the Moose River basin of northern Ontario, but much less is known about these deposits and they would be accessible only with considerable difficulty. Other smaller deposits of reasonably high-alumina clays in Nova Scotia, Quebec, Manitoba and British Columbia are, as far as is known, too small to be of interest as sources of alumina.

Certain waste materials associated with the coal industry are possible sources for alumina. These materials have the advantage of having already been mined and generally constitute a waste that would otherwise have to be discarded. One of these materials is fly ash, small spherical ash particles collected from the flue gases in coal-fired thermal electrical generating stations. In Alberta, the Sundance and Wabamun power stations west of Edmonton produce a total of over 600 000 t/a of fly ash containing about 23% alumina. The supply of fly ash here will increase with the opening of the Keephills generating station. Rejects from coal mining and coal washing operations provide a material that contains combustible matter to provide heat for calcination of the clay minerals which are the principal source of alumina in these rejects. Coal mines and preparation plants in southeastern British Columbia could supply coaly wastes with about 25 to 33% alumina in the ash. The Hat Creek deposit, about 193 kilometres northeast of Vancouver, is particularly interesting. This extremely large deposit, which may contain over 1 GIGA tonnes of mineable coal, has been considered for development to feed a thermal electrical generating station. The high alumina content (27 to 33%) of the inorganic material associated with the coal would make the coaly wastes from tnis development particularly attractive as a source of alumina.

A final possibility for a domestic source of alumina is nepheline syenite, an aluminum silicate rock containing about 20 to 28% aluminum oxide. The best-known deposits are those near Peterborough, Ontario, currently being worked to provide material that has a good market in the glass and ceramic industries and so would not be available as a source of alumina. Nepheline syenites with somewhat higher alumina contents are found further north near Bancroft. During the Second World War the Bancroft deposits were examined,

but the reserves here would be too small to support an alumina extraction industry.

Although Canada is not endowed with bauxite or large well-defined deposits of high-alumina clays, there are several fairly promising potential sources of alumina. Evaluations of some of these sources have been conducted at CANMET.

EXTRACTION OF ALUMINA FROM NON-BAUXITE SOURCES

Methods for the extraction of alumina from non-bauxite sources generally fall into one of two categories, the acid processes and the alkaline processes. In the acid processes the alumina is dissolved in a mineral acid, sulphuric, hydrochloric, or nitric, and then, after appropriate purification, separation and decomposition steps, is recovered finally as calcined aluminum oxide. The alkaline processes usually involve roasting or sintering the material with limestone and perhaps soda ash (sodium carbonate), followed by leaching, solution purification and alumina recovery. In another type of alkaline process, the hydrochemical process, the raw material is treated with concentrated caustic solution under pressure at elevated temperature. Both acid and alkaline processes were studied at CANMET in laboratory investigations on extracting alumina from samples of potential Canadian raw materials.

The Lime-Soda Sinter process for treating anorthosite has been investigated in considerable detail by the US Bureau of Mines, both by the operation of a 50 t of alumina per day pilot plant at Laramie, Wyoming, in the early 1950s and by several laboratory investigations during the 1960s. In this process the crushed and ground anorthosite is mixed with limestone and soda ash. The limestone reacts with the feldspar in the anorthosite on heating at about 1300°C, to form an insoluble calcium silicate, while the soda ash reacts to form soluble sodium aluminate. The sintered mass is crushed and the sodium aluminate is leached or dissolved out; after purification of the solution to remove dissolved silica, the alumina is recovered by precipitation and calcination. This process has been successfully applied to Canadian anorthosite at CANMET. In the Lime Sinter process only limestone, but no soda ash, is mixed with the anorthosite for sintering. The mixture, in cooling after sintering, disintegrates or decrepitates so that no grinding is required prior to leaching. The extraction of alumina, however, may be lower than that

achieved in the Lime-Soda Sinter process, depending on the composition of the anorthosite. Fly ash, when treated by the Lime Sinter process, also gives a sintered mass that decrepitates on cooling, but the extraction of alumina during the leaching step may be very poor. Research and development at CANMET has shown that if the lime sinter process is modified by the addition of an appropriate amount of soda ash (but in smaller quantity than would be added in the Lime-Soda Sinter process), improved alumina extraction can be achieved, while the sintered mass will still decrepitate on cooling. The removal of silica from the leach solution is necessary to obtain alumina of suitable purity for feed to the electrolytic aluminum cells. Silica removal, however, is a problem area with these processes.

Acid processes have been investigated for the treatment of clays, anorthosites and coal residues. Samples of Saskatchewan clays, after calcination at about 750°C, can be leached with hydrochloric, sulphuric or nitric acid to extract the alumina. Coaly wastes that contain large amounts of clay minerals, such as those from the Hat Creek deposit, are currently being investigated. These materials can be burned under controlled conditions chosen so that the clay components are calcined at temperatures low enough that the alumina is soluble in acid. The alumina in the ash remaining after combustion can then be extracted to give solutions similar to those obtained from the clays. Methods for purification of the acid solutions, precipitation, and recovery of cell-grade alumina have been studied by others, for example, the US Bureau of Mines, and Pechiney-Ugine-Kuhlmann in France in connection with the development of their H^+ process for acid extraction of alumina from clays. At CANMET work was done specifically on solutions obtained from Canadian raw materials.

Most anorthosites are quite resistant to attack by the common mineral acids. Certain anorthosites, those with a high alumina and calcium content, were found to be readily soluble in hydrochloric acid. The more resistant anorthosites, however, can be rendered susceptible to acid attack by fusion at very high temperature, followed by quenching to form a glass.

It is clear that there are several processes that might be used to treat the Canadian non-bauxite sources of alumina. There remain certain problems that have to be considered; for example, the sinter processes leave large quantities of residue after the alumina has been extracted, about 7 to 10 t of residue for each tonne of alumina recovered. In the acid processes,

impurities such as calcium, sodium and iron in some of the raw materials would consume acid which would have to be recovered and recycled. Careful consideration must be given to the relative costs of the various processes in order to identify the ones that would be most economical, and to attempt to compare these processes to the Bayer process using imported bauxite. This task is very difficult when only laboratory-scale data are available. It appears that coaly waste materials represent one of the better potential sources for alumina in Canada. More detailed investigations would be warranted on extraction methods for recovering alumina from these materials.

PROCESS REQUIREMENTS

A process which is trouble free in operation and produces a product according to specification, is not necessarily a process that is at the same time economically viable. "Economically viable" means that the production cost of a product is comparable to or lower than that of a product produced by existing process(es). In the case of alumina, production cost is often compared to the cost of alumina produced by the Bayer process from bauxite. There are many factors affecting production cost. Perhaps the most important factors are the cost of raw materials, reagents, energy and the plant costs. If we examine these factors briefly for the Bayer process and for processes with which we hope to replace the Bayer process, we find that the only cost which is high in the case of Bayer process is the cost of raw material (bauxite) and all the other costs are low. Nothing shows better than the simple table below the uphill battle we are facing in trying to replace the Bayer process and why we have failed so far to do so.

	Cost			
Processes	Raw Material	Reagent	Energy	Capital
Bayer with bauxite	high	low	low	low
Acid with non-bauxite materials	low	high-med*	high	high
Lime-Soda Sinter with non-bauxite materials	low	high	high	high

*depends on the Fe, Mg, Ca, Na, etc., content of materials

Extending the above table to specific raw materials, one can easily evaluate the economic viability of any raw material-process combination. The table below shows different raw material-process combinations.

Process and Raw Material Combination	Cost			
Acid process with	Raw Material	Reagent	Energy	Capital
Anorthosite	low	high	high	high
Clay	low	moderate	high	high
Coaly waste	low	moderate	low	high
Lime-Soda Sinter process with				
Anorthosite	low	high	high	high
Clay	low	high	high	high
Coaly waste	low	high	low	high

From the above table one can see that the only process-raw material combinations that have some chance of being economically viable are the

a. Lime-Soda Sinter process on coaly waste.

b. Acid process on coaly waste,

Of the above two processes only the sinter process is used industrially on fly ash and on a limited scale in Poland. CANMET investigation shows (3) that ash obtained from Hat Creek coaly waste is amenable to the Lime-Soda Sinter process (Fig. 1).

The deciding factor in favour of viability for both processes is the raw material coaly waste, which supplies most of the energy requirement for the processes and consequently reduces operating cost.

Because of the failure of an acid process (2,4) to produce cell-grade alumina from coaly waste, the author suggested the use of a HCl-Caustic Purification process on coaly waste. This process entails of solubilizing the alumina value of the ash in HCl and concentrating the liquor in order to precipitate $AlCl_3.6H_2O$, which then is roasted to produce a crude alumina with impurities (Fig. 2). This crude alumina is purified and processed in a modified Bayer process. This way the Al_2O_3 produced is most likely to meet specifications for cell-grade alumina (4).

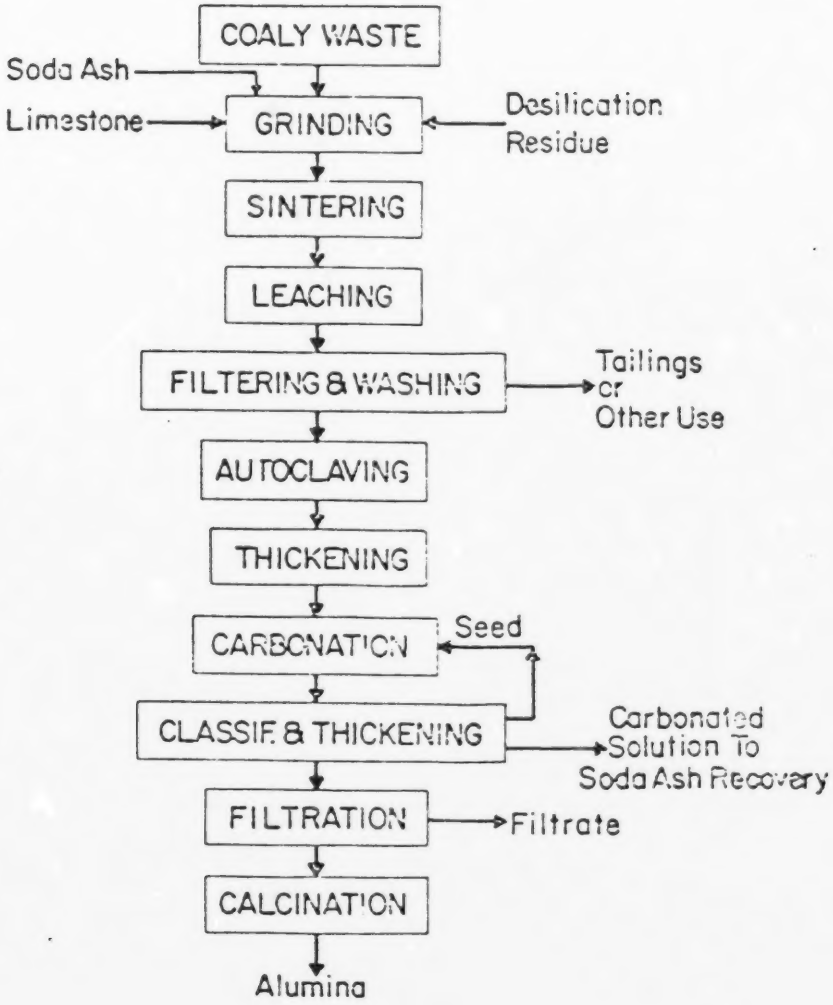

FIGURE 1. LIME-SODA SINTER PROCESS ON HAT CREEK COALY WASTE

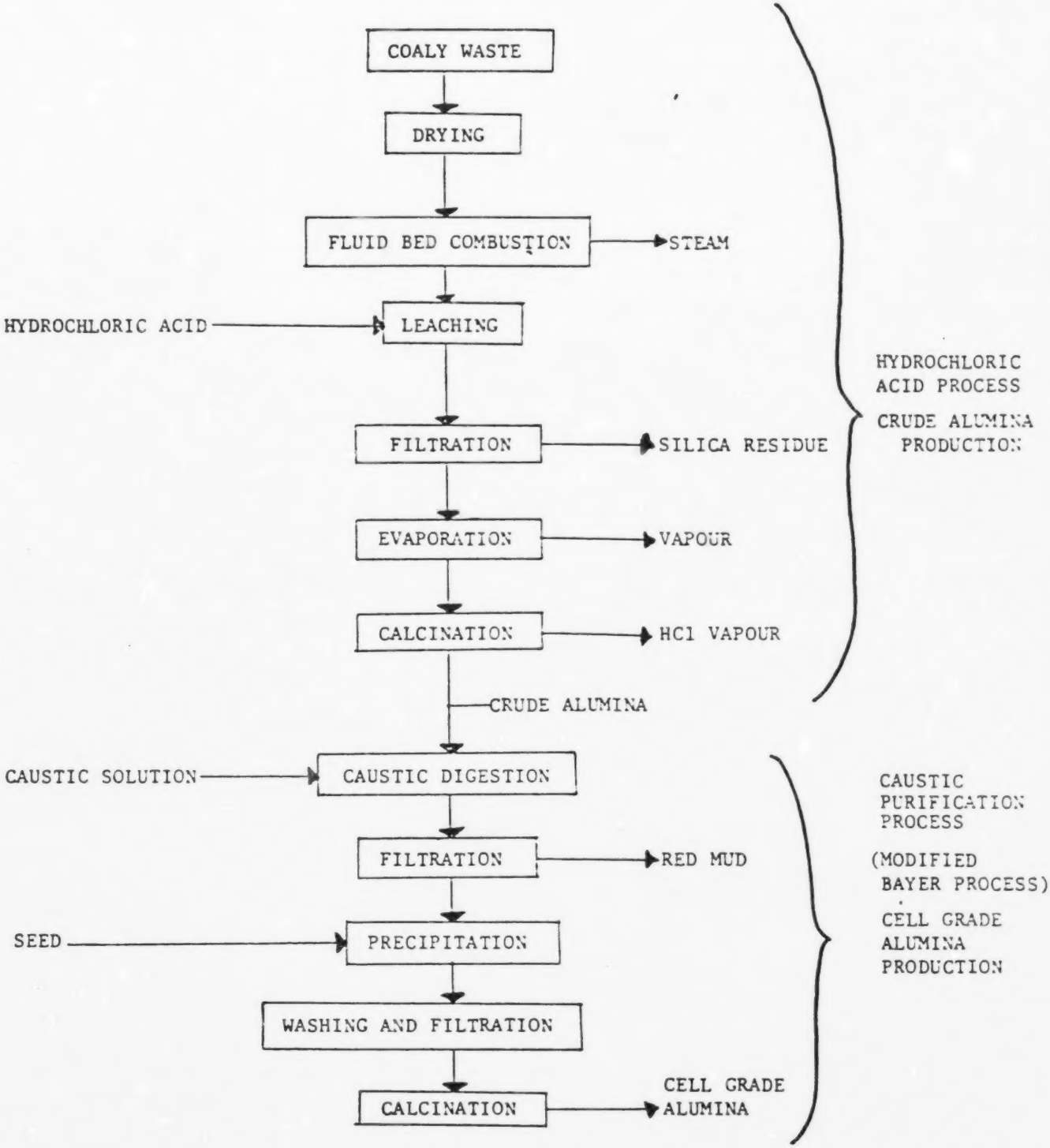

Fig. 2 - Hydrochloric Acid - Caustic Purification process for the recovery of alumina from coaly waste

CAPITAL AND OPERATING COST ESTIMATE FOR DIFFERENT PROCESSES AND RAW MATERIALS

All of the processes on clay and anorthosite have been evaluated by the US Bureau of Mines (7) many years ago and recently updated with respect to capital and operating costs using current M&S indexes and present labour and raw material costs.

In this instance capital and operating cost estimates are updated for the following processes (7):

a. Hydrochloric Acid-Caustic Purification process on clay (Table 2)
b. Lime-Soda Sinter process on clay (Table 3)
c. Lime-Soda Sinter process on anorthosite (Table 4)
d. Bayer process on bauxite (Table 7)

The capital and operating cost estimates for the HCl-Caustic Purification and the Lime-Soda Sinter process on coaly waste are contained in Division Reports from CANMET (5,6) and updated in Table 5 and 6 respectively.

Unit prices, for raw materials and utilities used in the calculations, are shown below:

Anorthosite	$3.50 per tonne
Coal	$1.00 per GJ
Clay	$2.00 per tonne
Coaly waste	$0.30 per tonne
Limestone	a) $4.60 per tonne for anorthosite
	b) $5.00 per tonne for clay and coaly waste
Soda ash	$110.00 per tonne (50% Na_2CO_3)
Electric power	$0.02 per kWh
Steam	a) $0.50 per tonne (from coaly waste burning or waste heat boilers)
	b) $8.96 per tonne (for purchased fuel)
Water, cooling	$0.02 per m^3
Water, process	$0.04 per m^3
Water, raw	$0.01 per m^3

Natural gas		$3.00 per GJ
Labour		$11.30 per man hour
HCl	18°Bé	$65.00 per tonne

Table 1 shows the fixed capital cost for an alumina plant producing 1000 tonnes alumina per day with different processes and raw materials. The same table also shows the operating cost per tonne of alumina.

Tables 2 - 7 show details of operating cost for each process and raw material.

DISCUSSION

Table 1 shows that the Bayer process on bauxite is the least capital intensive process but the production cost per tonne of alumina is lowest with the HCl-Caustic Purification process with coaly waste. There is a significant difference between the HCl-Caustic Purification process on clay and coaly waste. Both the capital and operating costs differ significantly for the same process but different starting material. The reason behind the difference naturally lies with the starting material coaly waste. It has substantial carbon content which on burning produces more heat, in the form of steam, than required for evaporation in a seven effect evaporation system. Therefore the seven effect evaporation system has been reduced to a three effect system, which in turn reduced the capital and operating costs by as much as 30%. This also explains why operating cost per tonne of alumina for the HCl-Caustic Purification system on coaly waste is less than for the Bayer process on bauxite.

CONCLUSION

The HCl-Caustic Purification process on coaly waste is the most likely process to produce cell-grade quality alumina economically. The next most likely process that could produce alumina economically is the Lime-Soda Sinter process also on coaly waste. The two above mentioned processes are economically viable on coaly waste only and not on clay or anorthosite because most of the energy required for the process is supplied by the residual combustible matter in the coaly waste.

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Table 1 - Summary of CANMET alumina process cost estimates

Raw materials and processes	Operating cost $ per tonne Al_2O_3	Fixed capital cost for 1000 t per day Al_2O_3 plant $ x 10^6
Clay ($2/t)		
HCl-Caustic Purification process	303.26	282.74
Lime-Soda Sinter process	291.06	208.70
Anorthosite ($3.5/t)		
Lime-Soda Sinter process	299.10	210.99
Coaly Waste ($0.3/t)		
HCl-Caustic Purification process	223.11	226.80
Lime-Soda Sinter process	256.59	221.61
Bauxite ($35/t)		
Bayer Process	228.01	141.48

Table 2 - Estimated operating cost for the Hydrochloric Acid-Caustic Purification process[1] on clay (7)

	Cost per tonne alumina
Direct cost:	
Raw materials:	
Raw clay at $2/t	$11.22
Hydrochloric acid 18°Bé, at $65/t	18.91
Sodium hydroxide at $250/t	11.96
Total	42.09
Utilities:	
Electric power at 2 cents/KWh	4.23
Steam, 100 psig, at $8.96/t	30.23
Water, cooling at 2 cents/m^3	3.13
Water, process at 4 cents/m^3	0.92
Water, raw, at 1 cent/m^3	0.05
Natural gas at $3/GJ	15.00
Coal $1/GJ	31.21
Compressed air at 2 cents/Mcf	0.04
Total	84.81
Direct labour:	
Labour at $11.30/h	36.68
Supervision, 15% of labour	5.50
Total	42.18
Plant maintenance, 4% of fixed capital cost	34.27
Operating supplies, 15% of plant maintenance	5.14
Total Direct Cost	39.41
Indirect cost, 50% of direct labour and maintenance	$35.47
Fixed cost:	
Taxes and insurance, 2% of total plant cost	16.47
Depreciation, 5% of fixed capital cost	42.83
Total Operating Cost	303.26

[1]Revised from BuMines RI 6133, using M and S Index correction to 1981 and 1981 chemical prices, labour rates, and utility rates.

Table 3 - Estimated operating cost for the Lime-Soda Sinter process,[1] wet-grinding option, for treating clay (7)

	Cost per tonne alumina
Direct cost:	
Raw materials:	
Clay at $2/t	$10.08
Limestone at $5/t	45.75
Soda ash at $110/t	25.26
Total	81.09
Utilities:	
Electric power at 2 cents/KWh	10.52
Steam, recovered, at $0.5 cents/Mlb[2]	3.18
Water, cooling, at 2 cents/m^3	0.90
Water, process, at 4 cents/m^3	0.70
Water, raw, at 1 cent/m^3	0.04
Natural gas at $3/GJ	15.00
Coal at $1/GJ	53.37
Total	83.71
Direct labour:	
Labour at $11.30/h	24.80
Supervision, 15% of labour	3.72
Total	28.52
Plant maintenance, 4% of fixed capital cost	24.44
Operating supplies, 15% of plant maintenance	3.66
Total Direct Cost	221.42
Indirect cost, 50% of direct labour and maintenance	26.48
Fixed cost:	
Taxes and insurance, 2% of total plant cost	$12.60
Depreciation, 5% of fixed capital cost	30.56
Total Operating Cost	291.06

[1]Revised from BuMines RI 6927, using M and S Index correction to 1981 and 1981 chemical prices, labour rates, and utility rates.

[2]Charge for water, chemicals, and labour used in producing steam in waste heat boilers.

Table 4 - Estimated operating cost for the Lime-Soda Sinter process, wet-grinding option, for treating anorthosite (7)

	Cost per tonne alumina
Direct cost:	
Raw materials:	
Anorthosite at $3.5/t	$18.76
Limestone at $5.0/t	48.56
Soda ash at $110/t	8.58
Total	75.90
Utilities:	
Electric power at 2 cent/KWh	17.86
Steam, recovered, at $0.5/Mlb[2]	3.36
Water, cooling, at 2 cents/m^3	1.00
Water, process, at 4 cents/m^3	0.52
Water, raw, at 1 cent/m^3	0.45
Natural gas at $3/GJ	15.00
Coal at $1/GJ	56.68
Total	94.87
Direct labour:	
Labour at $11.30/h	25.40
Supervision, 15% of labour	3.81
Total	29.21
Plant maintenance, 4% of total fixed capital cost	25.56
Operating supplies, 15% of plant maintenance	3.83
Total Direct Cost	229.37
Indirect cost, 50% of direct labour and maintenance	25.48
Fixed cost:	
Taxes and insurance, 2% of total plant cost	12.29
Depreciation, 5% of fixed capital cost	31.96
Total Operating Cost	299.10

[1]Revised from BuMines RI 7068, using M and S Index correction to 1981 and 1981 chemical prices, labour rates, and utility rates.

[2]Averages for water, chemicals and labour used in producing steam in waste heat boilers.

Table 5 - Estimated operating cost for the production of cell-grade alumina by the HCl-Caustic Purification process from coaly waste (5,7)

	Cost per tonne alumina
Direct cost:	
Raw materials:	
Coaly waste at $0.3/t	$3.33
Hydrochloric acid 18°Bé $65/t	18.91
Sodium hydroxide at $250/t	11.96
Total	34.20
Utilities:	
Electric power at 2 cents/kWh	5.52
Steam 684 kPa at $0.5/t	4.73
Water, cooling, at 1 cent/m^3	4.00
Water, process, at 4 cent/m^3	1.50
Flue gas at $0.2/GJ	5.07
Natural gas at $3/GJ	14.64
Total	35.46
Direct labour:	
Labour at $11.30/h	35.03
Supervision - 15% of labour	5.25
Total	40.28
Plant maintenance, 4% of fixed capital cost	27.49
Operating supplies, 15% of plant maintenance	4.12
Total Direct Cost	141.55
Indirect cost, 50% of direct labour and maintenance	33.88
Fixed cost:	
Taxes and insurance, 2% of total plant cost	13.32
Depreciation, 5% of fixed capital cost	34.36
Total Operating Cost	223.11

Table 6 - Estimated operating cost for the production of alumina by Lime-Soda Sinter process from coaly waste (6,7)

	Cost per tonne alumina
Direct cost:	
Raw materials:	
Coaly waste at $0.3/t	$3.33
Limestone at $5/t	45.76
Soda ash at $110/t	25.26
Total	74.35
Utilities:	
Electric power at 2 cents/kWh	12.0
Steam at $0.5/t	3.58
Water cooling at 2 cents/m^3	0.8
Water process at 4 cents/m^3	1.2
Raw water at 1 cent/m^3	0.04
Natural gas at $3/$J	15.0
Coal at $1/GJ	10.00
Total	42.62
Direct labour:	
Labour at $11.30/h	28.25
Supervision - 15% of labour	4.23
Total	32.48
Plant maintenance, 4% of Fixed Capital Cost	26.86
Operating supplies, 15% of plant maintenance	4.02
Total Direct Cost	180.33
Indirect cost, 50% of direct labour and maintenance	29.67
Fixed Cost:	
Taxes and insurance, 2% of total plant cost	13.01
Depreciation, 5% of fixed capital cost	33.58
Total	256.59

Table 7 - Estimated operating cost for the production of cell-grade alumina by the Bayer process from bauxite (7)

	Cost per tonne alumina
Direct cost:	
Raw materials:	
Bauxite at $35/t (30 + 5 for Transp)	$91.00
Limestone at $5/t	0.37
Soda ash at $110/t	8.24
Starch at $150/t	1.00
Total	100.61
Utilities:	
Electric power at 2 cents KWh	1.44
Steam, 2067 kPa, at $8.96/t	32.1
Water, cooling, at 1 cent/m^3	1.25
Water, process, at 4 cents/m^3	0.40
Natural gas at $3/GJ	12.68
Total	47.87
Direct labour:	
Labour at $11.30/h	12.48
Supervision, 15% of labour	1.87
Total	14.35
Plant maintenance, 4% of fixed capital cost	17.14
Operating supplies, 15% of plant maintenance	2.57
Total Direct Cost	182.54
Indirect cost, 50% of direct labour and maintenance	15.74
Fixed cost:	
Taxes and insurance, 2% of total plant cost	8.30
Depreciation, 5% of fixed capital cost	21.43
Total Operating Cost	228.01

POOR

QUALITY

ORIGINAL